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# Spacecraft Charging Results from the SCATHA Satellite


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15 March 1981



Interim Report





Prepared for

SPACE DIVISION
AIR FORCE SYSTEMS COMMAND
Los Angeles Air Force Station
P.O. Box 92960, Worldway Postal Center
Los Angeles, Calif. 90009

This interim report was submitted by The Aerospace Corporation, El Segundo, CA 90245, under Contract No. F04701-80-C-0081 with the Space Division, Deputy for Technology, P.O. Box 92960, Worldway Postal Center, Los Angeles, CA 90009. It was reviewed and approved for The Aerospace Corporation by G. A. Paulikas, Director, Space Sciences Laboratory, and J. R. Stevens, Principal Director, Space Test Directorate, Development Group. Major George A. Kuck, SD/YLXT, was the project officer.

This report has been reviewed by the Public Affairs Office (PAS) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

This technical report has been reviewed and is approved for publication. Publication of this report does not constitute Air Force approval of the report's findings or conclusions. It is published only for the exchange and stimulation of ideas.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Measurements made by surface potential monitors, contamination monitors, and electromagnetic interference monitors have successfully recorded the characteristics of satellite charging by the space environment. Differential potentials of several kilovolts have been measured between dielectric materials samples and space vehicle ground following the injection of energetic electrons around the vehicle. During some of these charging events, discharges have been detected.

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# PREFACE

We wish to acknowledge the dedicated efforts of N. J. Stevens, NASA Lewis Research Center; W. L. Lehn, Air Force Materials Laboratory; and all of the people in the Space Division Space Test Program Office, the Advanced Technology Division, and the Space Vehicle Subsystems Division, Martin Marietta Corporation and The Aerospace Corporation, who made this mission a success. The launch support and data acquisition were superbly handled by the Satellite Control Facility.

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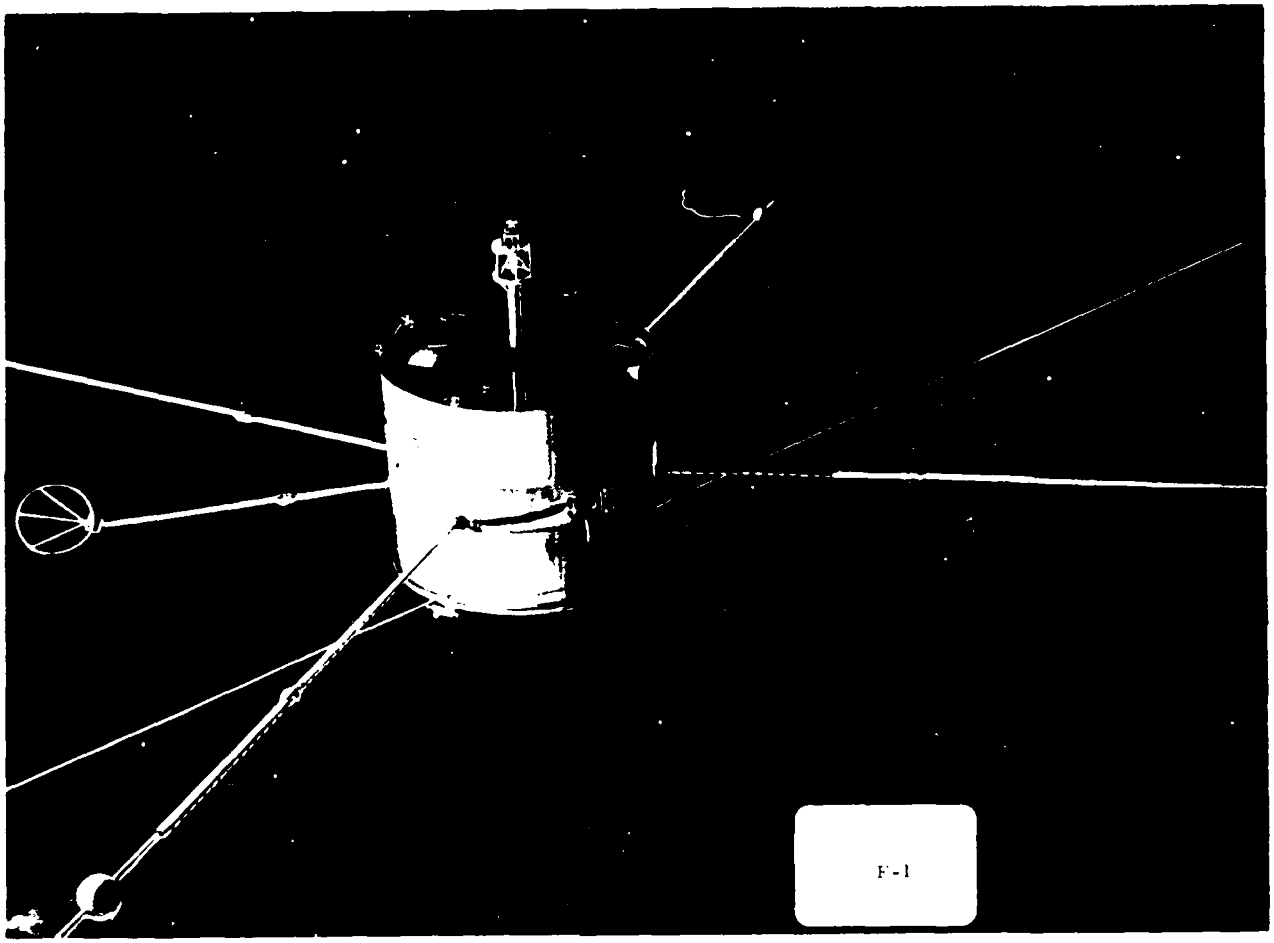
# INTRODUCTION

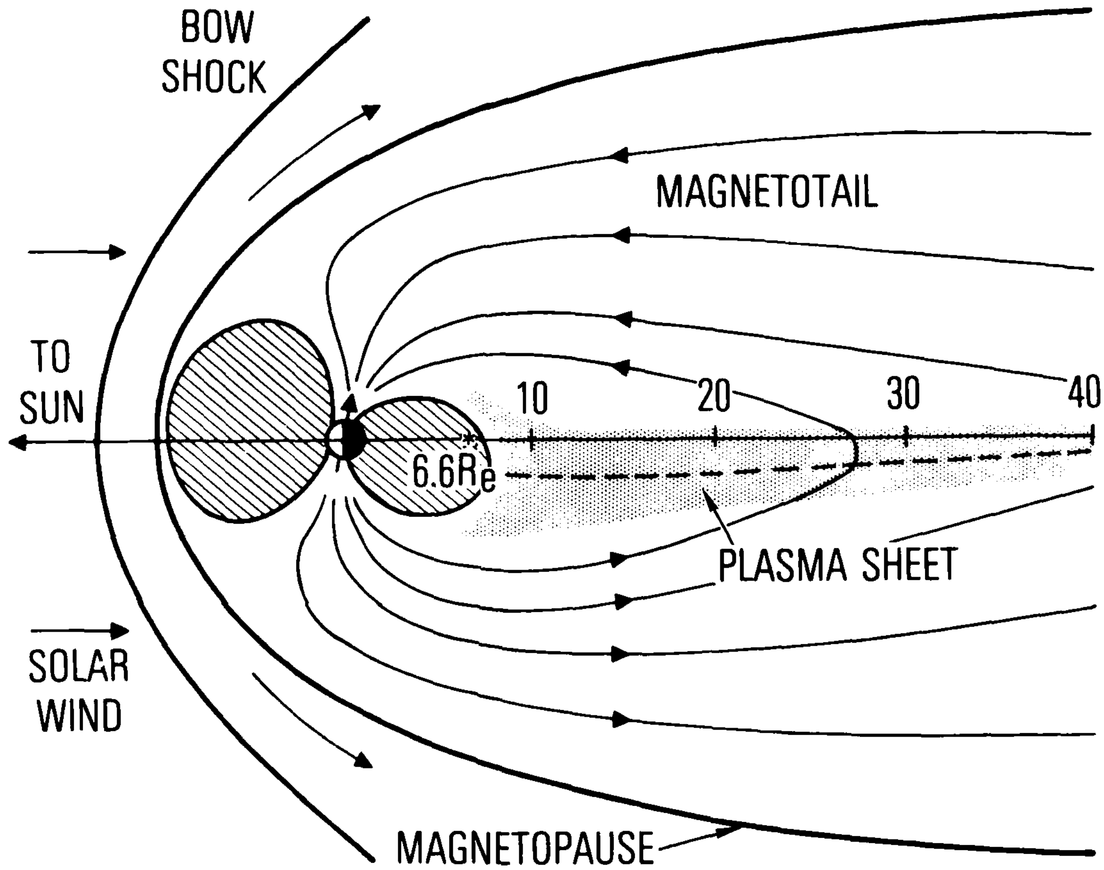
Engineering experiments aboard the U. S. Air Force SCATHA (P78-2) satellite (F-1), launched in January 1979, have successfully measured the characteristics of satellite charging by the space environment. These data will be used to specify test and design requirements for future satellites to eliminate disruption of mission performance caused by electrical charging of surface materials and the resulting discharges.

Measurements from previous satellites[1] have shown that potentials of several kilovolts are produced by energetic electrons. Electrical discharges between dissimilar materials charged to different potentials electrically couple into the spacecraft wiring harness. These electrical impulses may upset sensitive logic circuits. Large discharges may also degrade thin spacecraft surface coatings.

Satellite charging is closely associated with individual magnetospheric substorms. During geomagnetically active times the equatorial region on the night side beyond synchronous orbit fills with energetic electrons. The particles are called plasmasheet electrons (F-2). During injection events plasmasheet electrons are suddenly transported to lower altitudes, surrounding synchronous orbiting satellites. These energetic electrons are responsible for spacecraft charging. Although the mechanism for this injection is not known there is a statistical correlation with ground-based magnetometer measurements of magnetic substorms.




F-1  Artists conception of the SCATHA Spacecraft.



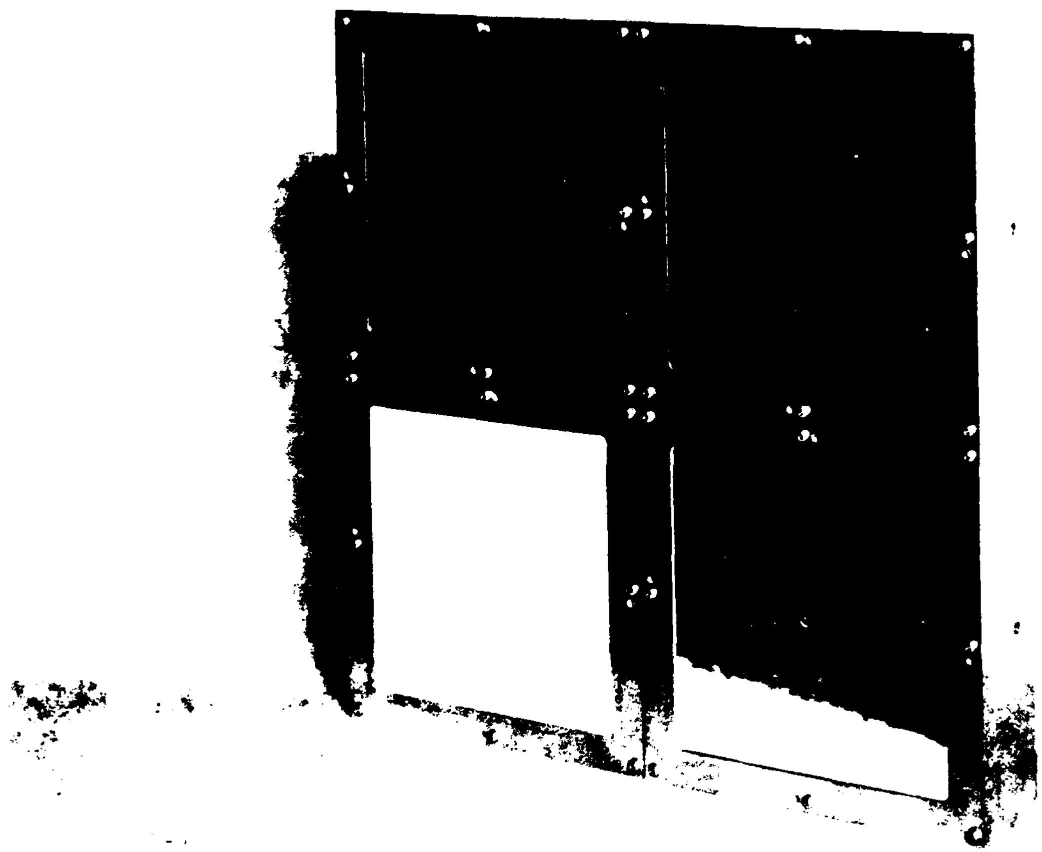

F-2 Schematic depicting plasma sheet electrons outside of synchronous orbit. During a geomagnetic storm these electrons are suddenly transported to lower altitudes where they can charge a satellite to several kilovolts.

Two of the engineering experiments on the SCATHA satellite are the Satellite Surface Potential Monitors (SSPM's) and the Charging Electrical Effects Analyzers (CEEA's). Three separate instruments (SSPM-1, -2, and -3) provide direct surface potential and bulk current measurements of typical spacecraft thermal control materials on a continuous basis. One of the SSPMs (-3) is shown in F-3. T-1 lists the sample materials and location of the SSPM instruments.

The Charging Electrical Effects Analyzer is used to verify that electrical discharges are occurring when the Surface Potential Monitors measure large differential potentials between surface materials and the vehicle. The CEEA consists of three instruments: a Pulse Analyzer, a VLF Analyzer, and an RF Analyzer. The Pulse Analyzer measures the amplitudes and shapes of discharges on four sensors. Two of the sensors are external and two internal to the spacecraft. The VLF Analyzer measures the electric and magnetic field spectra of waves in the frequency range from ~ 100 Hz to 300 kHz. The RF Analyzer measures the electric field intensity in the frequency range from 2 to 30 MHz using a 1.8-m monopole antenna.

Another experiment, the Sheath Electric Field Experiment, (SEFE) uses ion and electron measurements to infer the electric field in the plasma sheath near the satellite and the potential of the satellite with respect to the space plasma. It also measures the energy spectrum of the particles. This is an important parameter in the spacecraft charging process, since the level of charging is related to the average energy of the incident electrons.

There also is a contamination and thermal control coatings experiment on board in which two types of detectors are employed. One type is a hybrid instrument consisting of a Retarding Potential Analyzer (RPA) combined with a



F-3 One of the Satellite Surface Potential Monitor instruments.

T-1 Description and location of the material samples on the Satellite Surface Potential Monitors.

| SSPM | # | Description | Location |
|---|---|---|---|
| SSPM-1 | 1 | Aluminized Kapton | Perpendicular to Satellite Rotation Axis |
| | 2 | Optical Solar Reflector[a] | |
| | 3 | Optical Solar Reflector | |
| | 4 | Gold Plated Magnesium | |
| SSPM-2 | 1 | Aluminized Kapton[b] | $180^{\circ}$ from the SSPM-1 |
| | 2 | Aluminized Kaption | |
| | 3 | Reference Band | |
| | 4 | Reference Band[c] | |
| SSPM-3 | 1 | Aluminized Kapton | Parallel to Satellite Rotation Axis; Perpendicular to the Satellite-Sun Line |
| | 2 | Silvered Teflon | |
| | 3 | Quartz Fabric[d] | |
| | 4 | Gold Flashed-Aluminized Kapton | |

[a] Indium Oxide Coated and Grounded

[b] Large Sample with Hole

[c] High Gain

[d] Silvered Teflon Backing

Temperature Controlled Quartz Crystal Microbalance (TQCM). It is capable of weighing contamination and measuring the currents of charged particles which pass through a system of electrical grids. The other type of instrument is a set of eight calorimetrically-mounted thermal control coating samples. With it, changes in the solar absorptance to infrared emittance ratio of each sample are monitored. These changes are due to environmental and contamination effects and are of considerable interest to spacecraft thermal control engineers. Altogether there are four contamination detectors on the spacecraft - two of each of the two types.

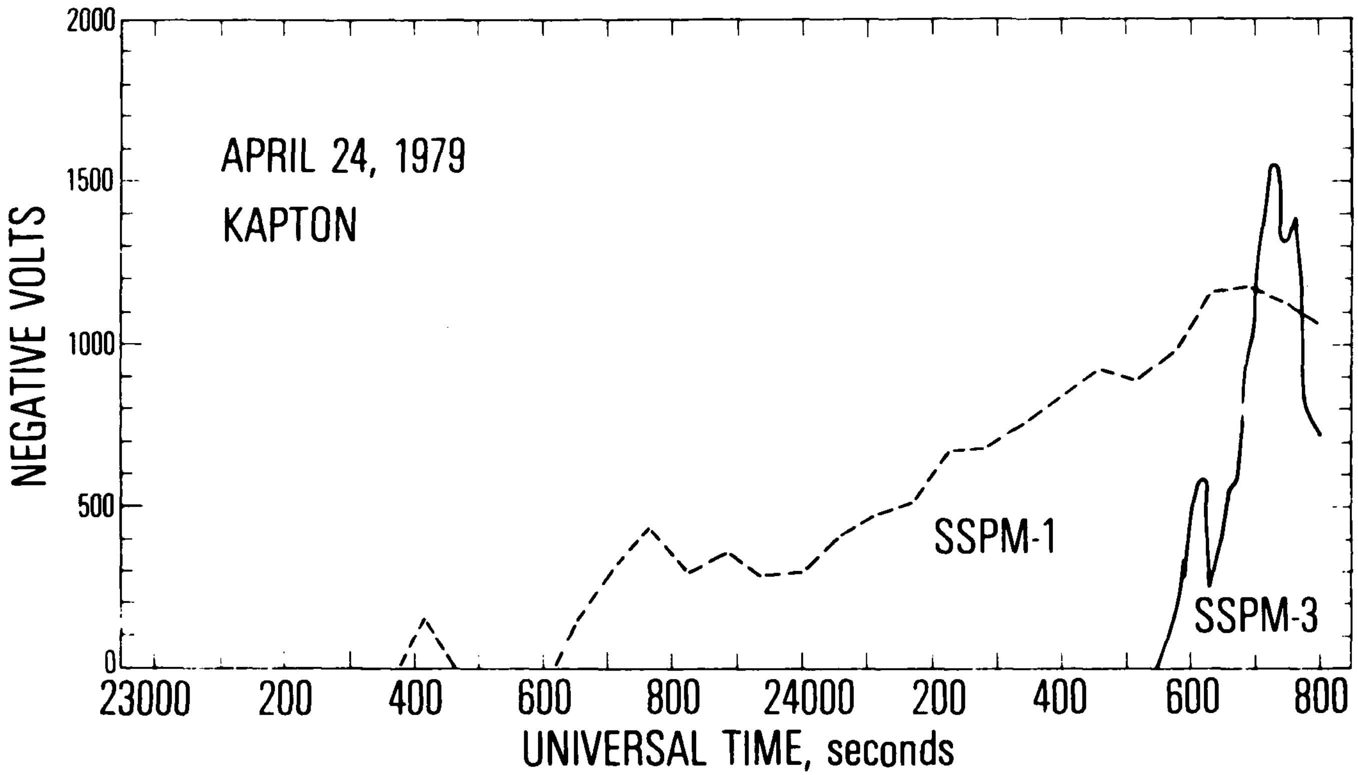
The instruments have been described in detail elsewhere.[2]

## OBSERVATIONS

Two natural charging events that took place on March 28 and on April 24, 1979, have been thoroughly analyzed.[3,4].

The event on April 24, 1979 was characterized by an intense plasma injection observed at the satellite before it entered eclipse. Before eclipse, all three of the Kapton samples on the SSPMs reached potentials greater than -1000 volts with respect to satellite structure ground. Teflon reached a potential as large as -6400 volts and the quartz fabric approached -3700 volts. F-4 shows the time averaged Kapton voltages for the beginning of that charging event. The SSPM-1 sample is on the cylindrical side of the spacecraft, rotating in and out of sunlight, while the SSPM-3 sample is on the end of the vehicle in shadow. The SSPM-3 sample begins to charge 1000 seconds after the SSPM-1 sample. In the earth's shadow, the satellite frame initially attained a potential with respect to the plasma of approximately -5000 volts.

Data from the charging event of 24 April 1979 has also been analyzed for evidence of an electrostatically induced enhancement of the rate of contamination collection by the two RPA/TQCMs. Presumably, a fraction of the heavy molecules outgassed by the vehicle during this period underwent ionizing collisions while still within the plasma sheath of the vehicle. (This fraction must have been smaller than usual, since photoionization, the major ionization mechanism, does not occur during eclipse.) The resulting positive ions would then be electrostatically attracted by the strongly negative exterior surfaces of SCATHA. Such an enhancement of the mass deposition rate was not observed during the charging event. However, because of eclipse induced thermal effects, the short-term detection threshold of the RPA/TQCM exceeded

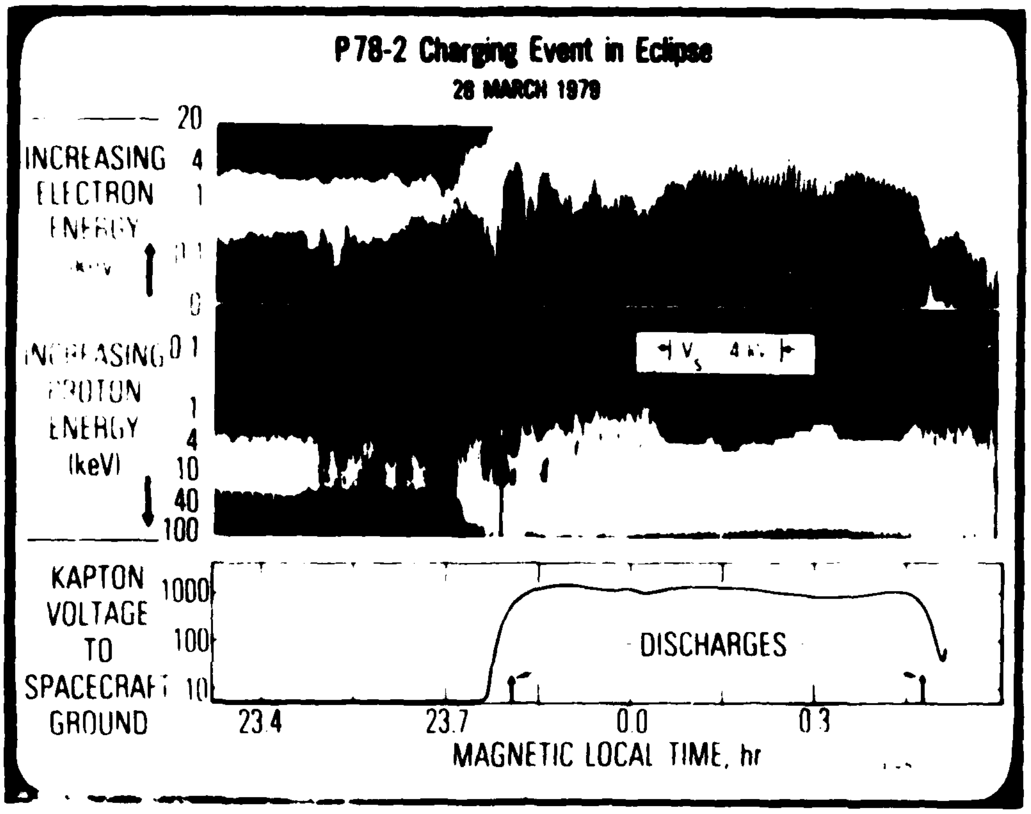



F-4 Kapton voltages with respect to the vehicle structure during a spacecraft charging event on April 24, 1979 when the vehicle was in sunlight.

the arrival rate of mass on the two RPA/TQCM detectors during that epoch by factors of 4 and 80. Therefore, only a very large increase in mass accumulation rate could have been detected, and the importance of spacecraft charging to contamination transport is not yet determined.

Data from March 28, 1979 were unusual in that the satellite was in the earth's shadow over 1000 sec before an injection of hot plasma near local midnight charged the vehicle negatively. F-5 shows a composite of data from the SSPM, the CEEA and the SEFE experiments. The differential potential between the Kapton sample (SSPM-1) and the vehicle frame is plotted as a function of time in the bottom panel. At the time the Kapton potential abruptly increases from background to over one kilovolt, the mean electron energy increases from about one kilovolt to greater than 20 kilovolts. About five minutes later a discharge was detected by the Pulse Analyzer. Later a second discharge and a decrease in the average Kapton potential occurs as the satellite crossed the terminator from shadow into sunlight. During this charging event, the vehicle frame increased to ~ -8000 volts and maintained a potential near -4000 volts until the spacecraft entered the sunlight. The data in F-5 confirm that the spacecraft charging induced by energetic electrons produced significant differential potentials and electrical discharges. The low energy limit of the protons in F-5 represents the potential of the spacecraft frame relative to the plasma environment. This is seen to fluctuate around ~-4 kV during the charging event. The potential between the dielectric surfaces and the plasma is found by adding the -4 kV of the spacecraft frame to the SSPM voltage.

The two pulses detected by the Pulse Analyzer during the March 28 event were undersampled in the logarithmic time spacing mode being used at the time. Hence frequency information cannot be obtained. Later in the mission




F-5 Electron and proton energy fluxes and Kapton voltages with respect to the vehicle structure during a spacecraft charging event on March 28, 1979 in the earth's eclipse. In the two top panels a brighter image represents greater particle fluxes. The sudden increase in the 4 keV electron fluxes near 23.7 local time corresponds to the injection of hot plasma which causes the charging. The modulation of the low energy boundary in the ion fluxes after 23.7 local time corresponds to the potential of the spacecraft frame. The ions from lower energies are accelerated up to an energy equal to the spacecraft potential.

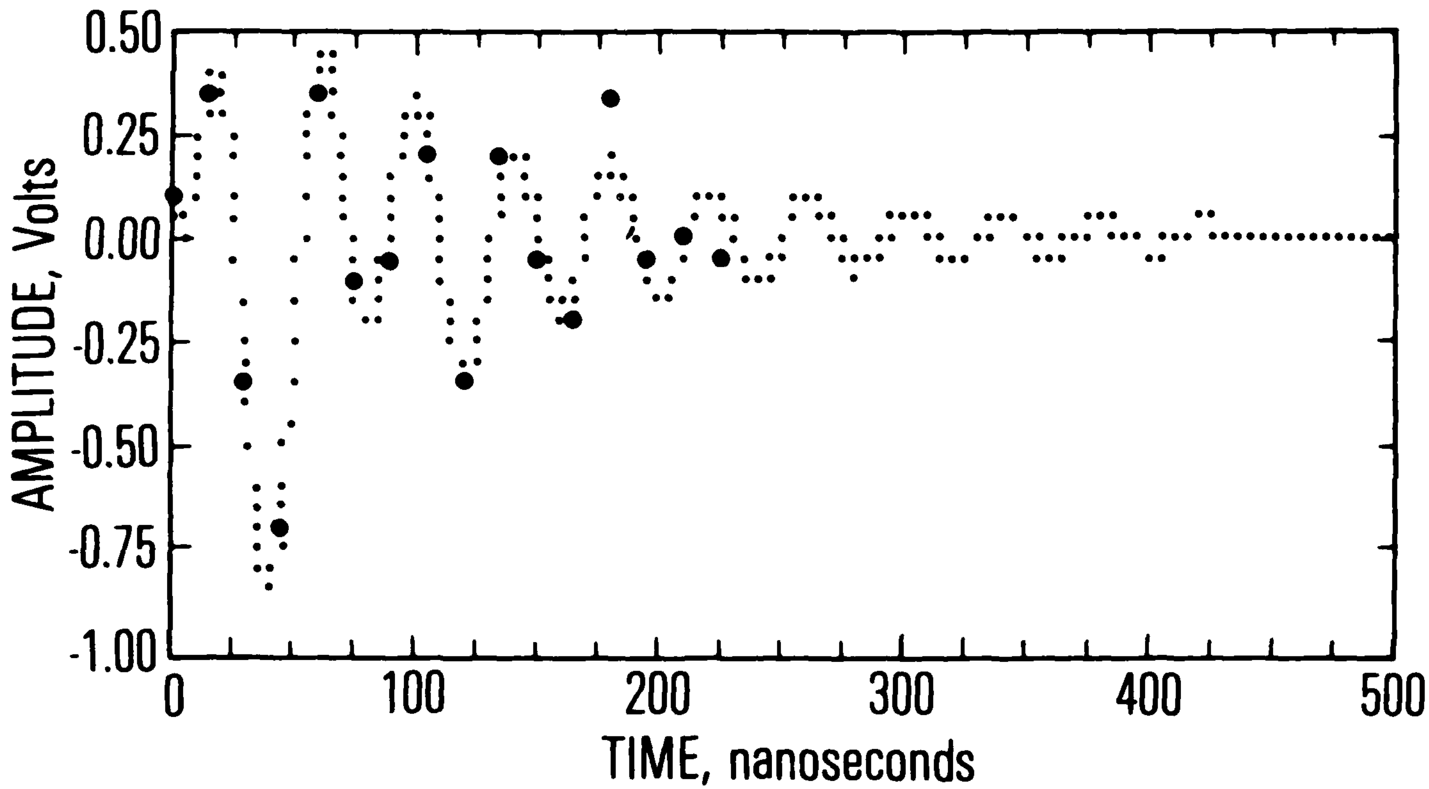
the Pulse Analyzer mode of operation was commanded to a linear sample spacing of 15 nanoseconds so that now we are able to resolve discharge pulse shapes.

On April 6, 1980 a pulse was detected on the external dipole sensor one minute and fifteen seconds after the satellite exited the umbra of the earth's shadow. For this discharge the Pulse Analyzer was in the linear mode. The data and the best-fit of a damped sine-wave function to the data are shown in F-6. The best fit was obtained using two frequencies of 11.1 and 25.0 MHz with amplitudes of 0.89 and 0.68 volts respectively.

One hundred and twenty-two days of Pulse Analyzer data have been analyzed for pulses. A total of 2150 were detected. All but fifteen of these occurred as a response to vehicle commands or experiment operations.

Although only a few natural discharges have been observed to date in the data from SCATHA, the number is adequate to account for some of the unexplained operations of synchronous orbit satellites.[5] However significant differential charging of materials has been observed without detection of discharge pulses above the threshold of the Pulse Analyzer.

SCATHA is successfully continuing its mission after 17 months on orbit. The data from SCATHA has verified and quantified the spacecraft charging mechanism. It has shown that materials at different locations on the vehicle charge to different levels at different rates, that even when the vehicle is in sunlight, shadowed dielectrics can charge with respect to the vehicle frame and the frame can charge with respect to the space plasma potential , and that material properties change in the space environment. The data is being used to develop better computer models of the interaction of a vehicle with the space plasma, to provide specifications for the electrostatic discharge testing of future vehicles, to improve spacecraft contamination management techniques and to design better laboratory testing programs.




F-6 Natural discharge detected on 16 April 1980 on the external dipole sensor. The 16 data points are identified by the larger symbols, the smaller points are a computer fit to the data.

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